TWENTY YEARS OF BAT MONITORING AT THE LONDON WETLAND CENTRE: SHOWING THE BIODIVERSITY VALUE OF A MAN-MADE URBAN RESERVE

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Abstract

We present the latest trends from 20 years of systematic bat surveys carried out at the London Wetland Centre (LWC), a man-made urban wetland reserve in west London. We also use a less systematic but wider-reaching bat dataset to provide context to the single site survey data and evaluate whether certain species are benefiting more than others from the reserve. Results showed that the LWC is particularly valuable for soprano pipistrelle *Pipistrellus pygmaeus*, Leisler's bat *Nyctalus leisleri* and Nathusius' pipistrelle *Pipistrellus nathusii*. Two species, brown long-eared bat *Plecotus auritus* and Natterer's bat *Myotis nattereri*, have been recorded in the Greater London area but remain elusive at the LWC. This provides some evidence that not all species will readily adapt to certain sites, even if a mixture of habitats is provided. Surveys at the LWC have shown the site continues to provide an important resource for many of London's bat species, as it has for two decades.

Introduction

As human populations increase, remaining wildlife habitat in major cities is often at risk of conversion to housing and the corresponding amenities, reducing the range of wildlife species able to maintain viable populations in these areas. Bats, which can act as an indicator species group for ecosystem health (Jones *et al*. 2009), are no exception to being vulnerable to this habitat loss. Urban bat populations often face pressure from light pollution (Stone *et al*. 2015), predation (Russo and Ancillotto 2015) and habitat loss. Being highly mobile means they are potentially able to relocate to other roosting sites and foraging grounds if offered a suitable alternative and are therefore well-suited to benefiting from interventions such as the creation of suitable habitats, providing these are sufficiently linked to roost and foraging sites via dark wildlife corridors.

Developing urban nature reserves is therefore a potentially valuable tool in maintaining biodiversity levels in human populated areas. However, differences between bat species have been observed in both use of habitat (Brooks 2009; Lookingbill *et al*. 2010) and response to urbanisation (Threlfall *et al*. 2012; Russo and Ancillotto 2015) indicating that not all species will benefit in the same way from such conservation interventions. In order to evaluate these interventions, long-term datasets of greater than or equal to 20 years (Meyer *et al*. 2010) are required to show how different species respond, independent of population fluctuations or seasonal trends.

Although studies on bats spanning multiple sites are common, many of these span only a single year (e.g. Oprea *et al*. 2009; Lookingbill *et al*. 2010; Threlfall *et al*. 2012) or several years (e.g. Erickson and West 2002; Gehrt and Chelsvig 2003; Brooks 2009; Borkin *et al*. 2011). In rare instances where more than a decade is covered (Ingersoll *et al*. 2013), limited resources and concerns for animal welfare (in the case of hibernaculum studies) often prohibit regular sampling. While short-term datasets are often sufficient for their intended purposes, such as habitat comparisons, they do not allow for thorough evaluation of a site colonisation or provide sufficient evidence for analysing the long-term differences in abundance between species. Although London is covered by the Bat Conservation Trust's National Bat Monitoring Programme (NBMP) which provides valuable information at the national scale through estimating changes in populations of ten bat species or species groups across over 3,000 sites since 1997 (Barlow *et al*. 2015), datasets that collect more detailed information at a local scale over this timeframe are rare.

In this paper we present results from a dataset comprising more than 20 years of regular bat surveys at the Wildfowl and Wetlands Trust London Wetland Centre, providing an update to earlier work by Briggs *et al*. (2007). The previous study looked at trends from ten years of data, covering the period 1997-2006, based on data from monthly transect surveys from June to September as surveys were carried out in these four months in all years. This latest study updates the trends using a further ten years of data and with a larger sample size for each year (data from monthly surveys carried out from March to October) in order to give more statistically robust results. For the latest analysis, 1998 was used as the start year as this was the first year in which March to October surveys were carried out following standardised transect routes.

By using regional data for the surrounding area to place these results in context, we are able to demonstrate the importance of the site to local biodiversity, as well as the value of maintaining long-term survey programmes. We also provide evidence that the value of the study site varies from species to species, with those species known to prefer wetland habitats predictably taking greater advantage of the site.

Methods and Materials

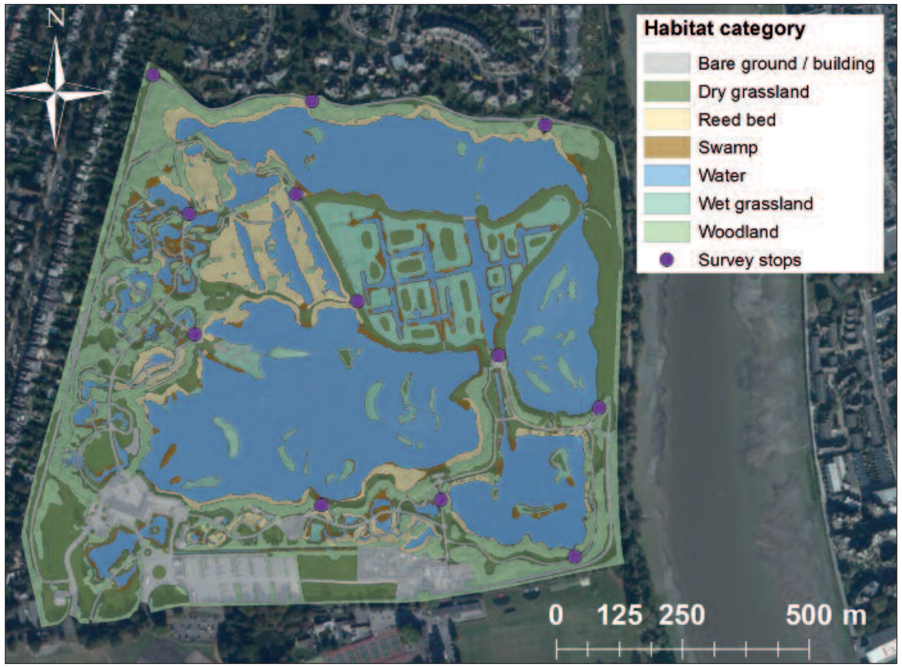
Study site

The Wildfowl and Wetlands Trust London Wetland Centre, shown in Figure 1, is an artificial nature reserve built on the site formally occupied by Barn Elms Reservoirs, a Victorian reservoir complex. As wetlands and aquatic habitats have been proven as valuable foraging grounds for many bat species (Brooks 2009) it was expected that development of the site would benefit local bat populations.

Development occurred between November 1995 and May 2000. The planting establishment and colonisation by vegetation on the largely non-vegetated reserve (1997-1999), in conjunction with phased flooding of water bodies during the late 1990s, aimed to provide a variety of wetland/terrestrial communities by the year of opening to the public in 2000. The establishment and maturation of both flora and fauna on site has been described elsewhere (Gilbert and Anderson 1998; Branson 2000; France 2011; Henderson and Rainbow 2012). With the establishment of vegetation communities on site, the first LWC five year management plan covering 2003-2007 was successfully implemented by WWT. The site is bordered on one side by the River Thames which is likely to be one of the key access routes for bats roosting in nearby parks. A road and playing fields neighbour the southern boundary with residential houses and gardens on the remaining two borders. Being only 7 km west-south-west from central London, the surrounding area is largely suburban in nature with a higher urban gradient just across the river from the site in the inner London Borough of Hammersmith and Fulham.

Several bat species are documented as having been present at Barn Elms Reservoirs prior to re-development. A survey in 1990 identified four species of bat: noctule *Nyctalus noctula*, serotine *Eptesicus serotinus*, Daubenton's bat *Myotis daubentonii* (Figure 2) and

Figure 1: The Wildfowl and Wetlands Trust London Wetland Centre is located just outside the highly urbanised landscape of inner London. Habitats mapped by Miller (2006).



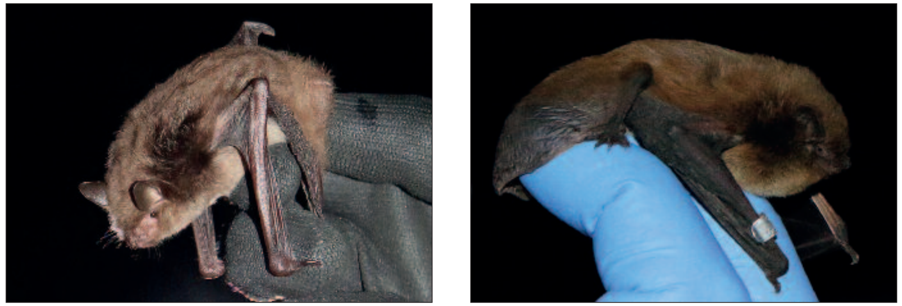


Figure 2: Daubenton's bat (left) and Nathusius' pipistrelle (right) caught in a harp trap at LWC in 2017. © Richard Bullock.

pipistrelle species *Pipistrellus* sp. (Mickleburgh 1990). This survey and subsequent surveys in 1992-3 (Hewlett 1992; Catto 1994) demonstrated that substantial numbers of bats foraged over the reservoirs. Seven species are now regularly recorded on the redeveloped site. Two species, soprano pipistrelle and Daubenton's bat, are known to be strongly associated with wetland habitats (Vaughan *et al*. 1997). The remaining species are noctule, common pipistrelle *Pipistrellus pipistrellus*, Leisler's bat, Nathusius' pipistrelle (Figure 2) and serotine. There have also been two sightings of brown long-eared bat. In March 2016, a Nathusius' pipistrelle roost was identified on site but there have been no further signs of use to date.

Data collection and preparation

Monthly surveys were carried out from March through to October between 1998 and 2016. When heavy rain was forecast or temperatures were predicted to fall below 8oC, surveys were rescheduled. Surveys began shortly after sunset and took one hour. Several meteorological variables were recorded at the beginning of each survey including maximum daytime temperature, temperature at the start of the survey and wind direction. Cloud cover was estimated visually based on oktas (See *et al*. 1986) and wind speed estimated using the Beaufort scale (Barua 2005). Surveys were not conducted in March of 2010, 2011 or 2013 due to overly cold temperatures. Two routes were covered on each survey with each starting at the same time (data for Route B on the October 2010 survey have been lost). Each route was divided into six transects on which a timed walk lasting seven minutes is carried out with a three minute stop at the end of each transect. Stop locations were selected that ensured all habitats on sites were represented and were evenly distributed where possible (see Figure 1). Euclidean distances between stops varied from 125 m to 290 m.

For each transect, heterodyne bat detectors were used to identify and count the number of individual bat passes for each species. The maximum number of individuals of each species seen at any one time was also recorded. Passes were defined as more than two consecutive echolocation calls (Thomas 1988). In instances where bat passes were continuous, these were recorded as such and interpreted at the standard rate of 12 passes per minute (Bat Conservation Trust 2007). Where a species could not be clearly identified, it was listed as either an unknown big bat (noctule, Leisler's bat or serotine) or unknown pipistrelle. Where a confident decision could not be made between noctule and Leisler's bat, this was recorded as 'noctule/Leisler's bat'. The same recording technique was used during the three minute stops.

Recording was carried out by staff and volunteers ensuring at least one surveyor on each route had experience in identifying bat species in order to give an expert opinion on identifications made by less experienced surveyors. For this study we included only records that contained a specific positive identification, discarding records where species were listed as 'unknown' or where two possible species were listed (most commonly 'noctule/Leisler's' bat). Individual species passes were capped at 84 passes per section and 36 passes per stop, consistent with the values for continuous sightings.

To place the LWC data in context, bat records in the area surrounding the Centre were obtained from GiGL CIC (Greenspace information for Greater London Community Interest Company), who collate information on recorded bat activity in Greater London from various sources (GiGL 2017). The data from GiGL were analysed to produce trends in annual numbers of records for each species. Any data originating from the LWC were removed from the GiGL dataset before the analysis so as not to bias the comparison. Several records were also removed that were recorded within 20 m of the LWC on the evening when a survey was taking place as these were assumed to be errors in the location. GiGL data were also examined for any species that are present in Greater London but not recorded at the LWC.

Data analysis

Temporal trends for each species were examined with generalised additive mixed models, using the mgcv package in R (Wood 2006). The response variable was the capped total count of bat passes in each monthly survey. We used thin-plate spline smoothers to estimate the association with *year* and *month*. For the *year* smoother, we used generalised cross-validation to automatically select the optimal number of knots, whereas for *month* we set the number of knots = 3. We allowed for temporal autocorrelation in the data series by modelling an autoregressive time component. For each species, we examined Poisson and negative binomial distributions, and we compared first, second and third order autoregressive functions. For each species we selected the most appropriate of these models using AICs and visual inspection of diagnostic plots and partial autocorrelation function plots.

The effect of nightly weather conditions (wind speed, direction and cloud cover) was examined using generalised linear mixed models (GLMM), implemented in R using the glmmPQL function in the MASS package (Ripley *et al*. 2013) and a Gaussian distribution. The response variable was total passes per survey and the independent variable was wind speed, wind direction or cloud cover. Year and month (encoded as categorical variables) were included as random effects and interactions between variables were not examined. We ran an additional GLMM modelling with wind speed grouped into either 'high wind speed' of 3-4 oktas or 'low wind speed' of 0-2 oktas. As different species may react differently to weather conditions (either directly or as a result of how their prey reacts), we used only data from the most common species (soprano pipistrelle). Temperature variables were not examined due to their high association with the time of year (month).

To place the LWC results in context with the wider trends in Greater London, the number of total yearly records from the available GiGL data covering the same time frame (1998-2015, as data were not available for 2016) was plotted overlaying the LWC data. GiGL data were analysed for both the entire Greater London area, as well as restricted to within a 10 km radius of the study site. The additional analysis of only the local area allowed for a comparison of the LWC data with general London trends as well as on a more local scale to the LWC. For this, 10 km was considered a suitable radius as this includes nearby Richmond Park, where bats are known to roost, and covers the expected range any species would travel in a single evening.

Results

After removing passes without positive species identification, 70,362 out of 77,493 recorded passes were included in the dataset, covering 138 one hour surveys. For all species there were significant trends in activity levels over the period 1998-2016 (Table 1).

Species	Modelled distribution	Adjusted R2	P-value	
			Year	Month
Soprano pipistrelle	Poisson	0.29	<0.0001	0.007
Nathusius' pipistrelle	Negative binomial	0.32	<0.0001	0.059
Common pipistrelle	Negative binomial	0.16	<0.0001	0.15
Daubenton's bat	Negative binomial	0.13	0.00047	0.029
Leisler's bat	Poisson	0.27	0.0019	0.00038
Noctule	Poisson	0.38	<0.0001	0.38
Serotine	Negative binomial	0.13	<0.0001	0.0086

Table 1. Results of GAMM models of bat species activity levels at the LWC: 1998-2016.

Most species showed some significant monthly variation within years but this was minor compared to the annual variation. Soprano pipistrelle, common pipistrelle, Daubenton's bat, Leisler's bat and serotine all increased dramatically from 1998 to *c*.2005 (Figure 3). Leisler's bat numbers remained stable thereafter, whereas the other four species decreased markedly and at the end of the recording period were substantially scarcer than during the peak period (*c*.2004-6). From 2008-16 soprano pipistrelle numbers stabilised, whereas common pipistrelle increased. Daubenton's bat abundance appeared to stabilise from *c*.2013 but serotine numbers decreased to virtually zero by the end of the time series. Nathusius' pipistrelle abundance increased throughout the recording period and noctule abundance decreased, although there were indications of a recovery in noctule numbers in the final *c*.5 years of the time series.

Total passes per survey, as well as the total number of records for the surrounding area are given in Figure 4, along with total records for the local area and Greater London.

Trends for the LWC, the local area and Greater London generally were similar for soprano pipistrelle and Daubenton's bat, with soprano pipistrelle showing a sharp increase before declining around 2007, after which recorded numbers stabilised. The same decline seen for serotine at the LWC is evident in the results from the Greater London area. The

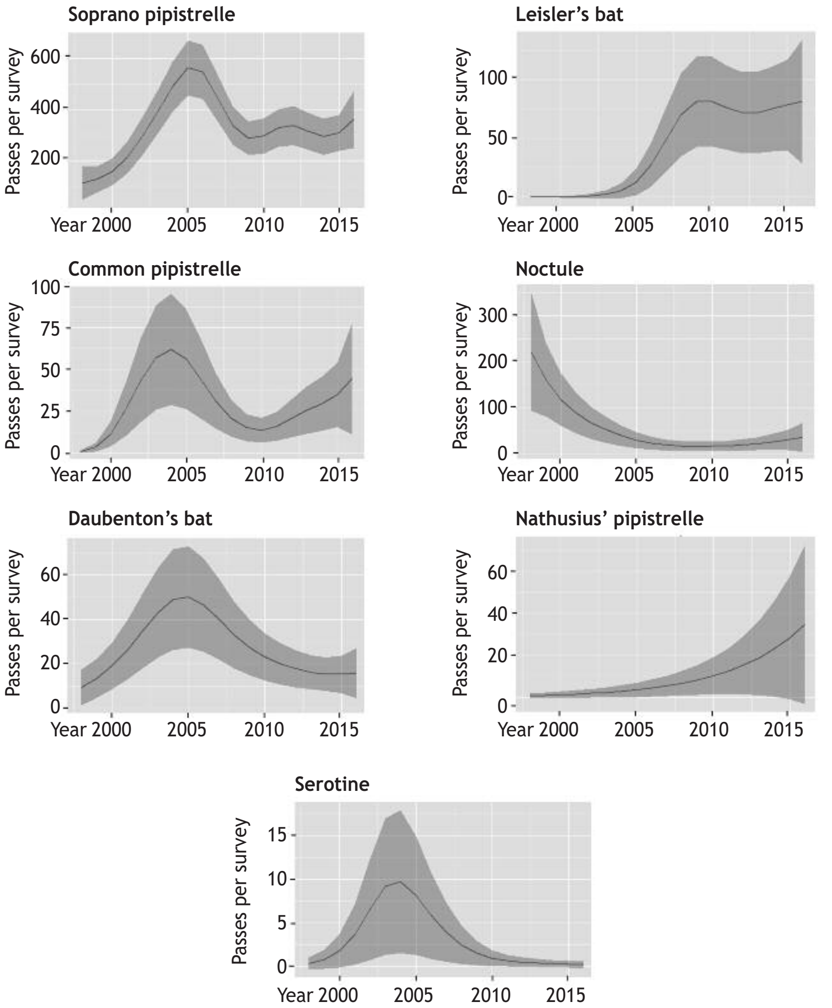


Figure 3: Modelled activity of bat species at the LWC. Graphs show predicted annual mean values from GAMMs, with shaded 95% CI's.

apparent increase in common pipistrelle in the wider area was not obvious from the LWC plots but was detected in the statistical trends (Figure 3). The sudden decline of noctule detected at the LWC in 2005 (around the same time Leisler's bat was first identified) is not apparent in the data for Greater London.

Two species, brown long-eared bat and Natterer's bat, were recorded in Greater London (Figure 5), but remain elusive at the LWC (no records of Natterer's bat and only two single sightings of brown long-eared bat).

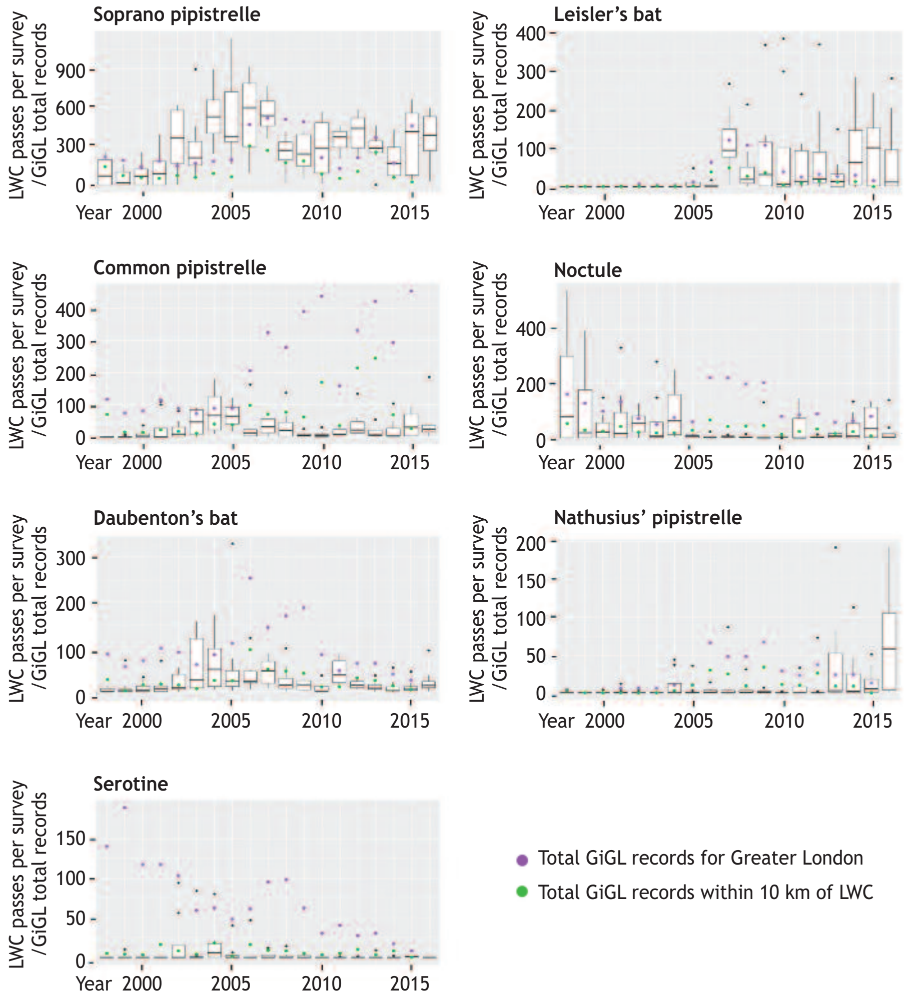
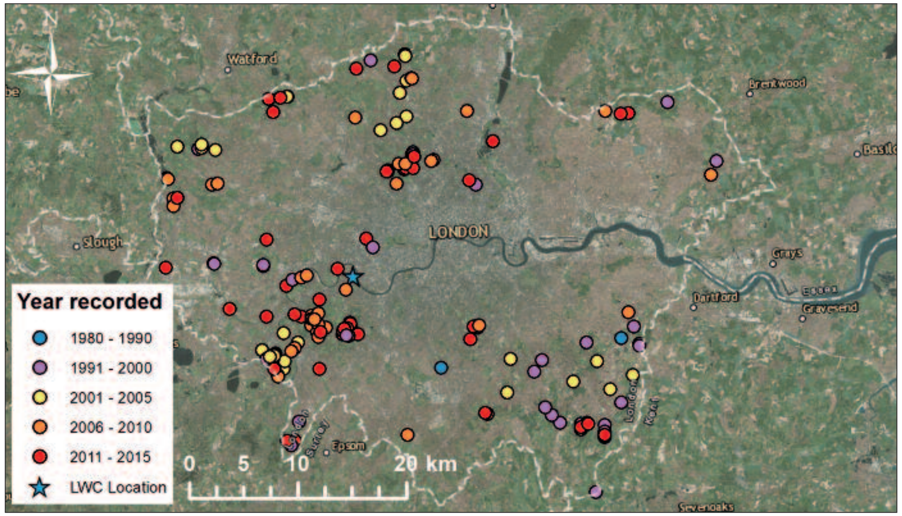


Figure 4: Species trends from 1998–2016 for the LWC, the local area (10 km) and Greater London. Boxplots showing passes per survey at the LWC represent minimum, first quartile, median, third quartile and maximum survey values for the year. Outliers are shown as black dots. Total records reported to GiGL are shown in purple and green dots.

Passes for soprano pipistrelle accounted for 47,324 out of 70,362 passes recorded. When year and month were accounted for, no significant associations were found between total passes and either wind speed (minimum p-value 0.078), grouped wind speed (p-value 0.61), wind direction (minimum p-value 0.078) or cloud cover (p-value = 0.2581).



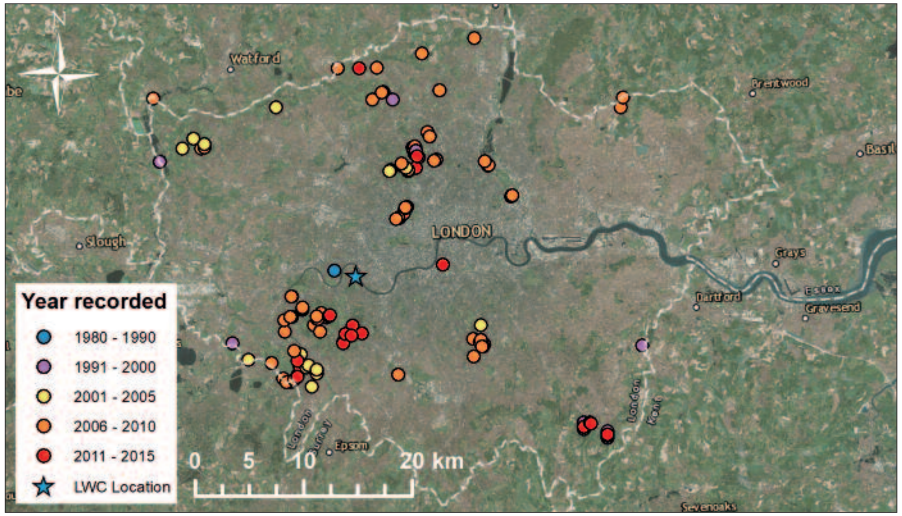


Figure 5: GiGL records for brown long-eared bat (top) and Natterer's bat (above) showing them to be present in the surrounding areas.

Discussion

Consistent, long-term surveys, such as those at the LWC, allow for trends in species to be examined beyond regular fluctuations in populations (Gehrt and Chelsvig 2003). This is evident in the analysis presented here in the differences shown between species. While some species were detected on site from the time it was established, others such as Leisler's bat and Nathusius' pipistrelle were not recorded regularly for the first seven

years. Nathusius' pipistrelle, while recorded occasionally on site for the first decade of the study, showed substantial increases in site usage only after 15 years. The length of the study period also allows the decline in serotine to be reasonably seen as a worrying trend rather than a natural fluctuation in population size. We found no relationship between abundance of soprano pipistrelle and either wind or cloud cover. This supports previous findings that these weather-related factors do not have a major impact on nightly bat abundance (Erickson and West 2002).

While a valuable source of information, there are several caveats with the interpretation of the GiGL dataset. Firstly, as the data originate from several sources, differences in the number of records from year to year may be a result of changes in survey effort and levels of data sharing. Furthermore, the level of survey effort across the region may be uneven. For example, the borough of Ealing, approximately 3.25 km north-west of the study site, has been flagged as being poorly surveyed (Law 2015). Secondly, in most cases the data contain only the number of records for a species, rather than the number of individuals or levels of activity and should therefore not be interpreted as abundance data in the strict sense. The data are however still useful for providing context to many of the trends identified at the LWC.

The trends for noctule and Leisler's bat, for instance, show an interesting interaction. Data from the study site show a steady trend in noctule activity at the site until 2004, when it drops suddenly without fully recovering. In contrast the GiGL data show an increase in noctule records after 2005. While an increase in noctule records in the GiGL dataset may reflect either a genuine increase in numbers or an increased survey effort, it is interesting that Leisler's bat is not recorded more than sporadically in either dataset until 2006. This might suggest that the species began using the site almost immediately after a possible recent population distribution spread to Greater London, although this could also reflect, in part at least, advances in species identification technology and skills possessed by contributors to the GiGL dataset. However, whereas Leisler's bat records across Greater London have declined in recent years, counts at the LWC remain stable.

A similar pattern is seen for Nathusius' pipistrelle, where a decline in London records contrasts with an increase at the study site. This is indicative that the LWC is likely to be an important site for this species. However, Nathusius' pipistrelle has a strong association with large water bodies, and other important sites for this species are known across Greater London, the region being something of a hotspot for the species (Bat Conservation Trust 2017). It may be that the annual number of records for this species in the GiGL database in part reflects how well other key sites for this species are represented in the GiGL data from year to year. For soprano pipistrelle, trends in the LWC site data closely match those of both Greater London and the local area, suggesting that the regular monthly surveys at the LWC could potentially be used as an indicator for more general London trends. It is also an indication of the importance of the site to this species.

Brown long-eared bat and Natterer's bat have not been confirmed as regularly occurring at the LWC despite their presence as breeding species within the borough of Richmond-upon-Thames, including the occasional record in close proximity to the site. There are several plausible reasons for this disparity. Brown long-eared bats avoid areas of high artificial light (Rydell 1992) and may therefore avoid the LWC which, being a small site with large areas of open water and surrounded by residential areas, is heavily affected by light pollution. Alternatively it may be due to their tendency to forage in woodland (Entwistle *et al*. 1997). While woodland habitats are present at the LWC, larger woodland areas are available in darker, neighbouring parks which may be preferable for these two species.

It is also possible that these species may frequent the site, but are emerging too late to be encountered on the surveys, or their calls are too quiet to be picked up by the bat detectors or too similar to other species' calls to be correctly identified in the absence of clear visual clues. Both species emerge later than other species identified on the surveys. Brown long-eared bats do not emerge from roosts until an hour after sunset, which is believed to allow them to avoid the twilight period (Entwistle *et. al*. 1996; Rydell *et al*. 1996). This species has sensitive hearing meaning it is able to detect prey via passive listening rather than echolocation, making them difficult to pick up on the surveys (Anderson and Racey 1993). When the species does use echolocation, the calls are low intensity and can only be detected over short distances (Anderson and Racey 1991). While Natterer's bat does not use passive listening, it too is a gleaning bat that will take prey very close to vegetation (Siemers and Schnitzler 2000) and as a result its calls can be quiet compared to other species on site, causing issues with detection. Furthermore, Natterer's bat calls are similar to those of Daubenton's bat which may result in its presence being overlooked. However, several harp trapping surveys carried out at the LWC have failed to catch any brown long-eared bats or Natterer's bats, which supports the assumption that they do not regularly occur at the site.

Conclusion

The data presented here from the LWC monthly bat surveys demonstrates the value of consistent, long-term monitoring of wildlife populations. It also shows variations in the extent to which different bat species have utilised the site, with some species readily utilising the site as soon as the new wetland habitat was created and others being recorded only after several years, while a couple of locally recorded species remain elusive. Overall, the site has been proven to provide foraging habitat for the majority of species found in London and can claim to be a site of regional importance for London's bats, especially soprano pipistrelle, Leisler's bat and Nathusius' pipistrelle.

Acknowledgements

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